

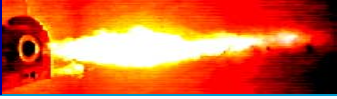
Tunable Diode Laser Sensors for Monitoring and Control of Harsh Combustion Environments

by W. Von Drasek

DOE/OIT Sensors and Controls '01

**Annual Meeting
New Orleans, LA
June 6-7, 2001**





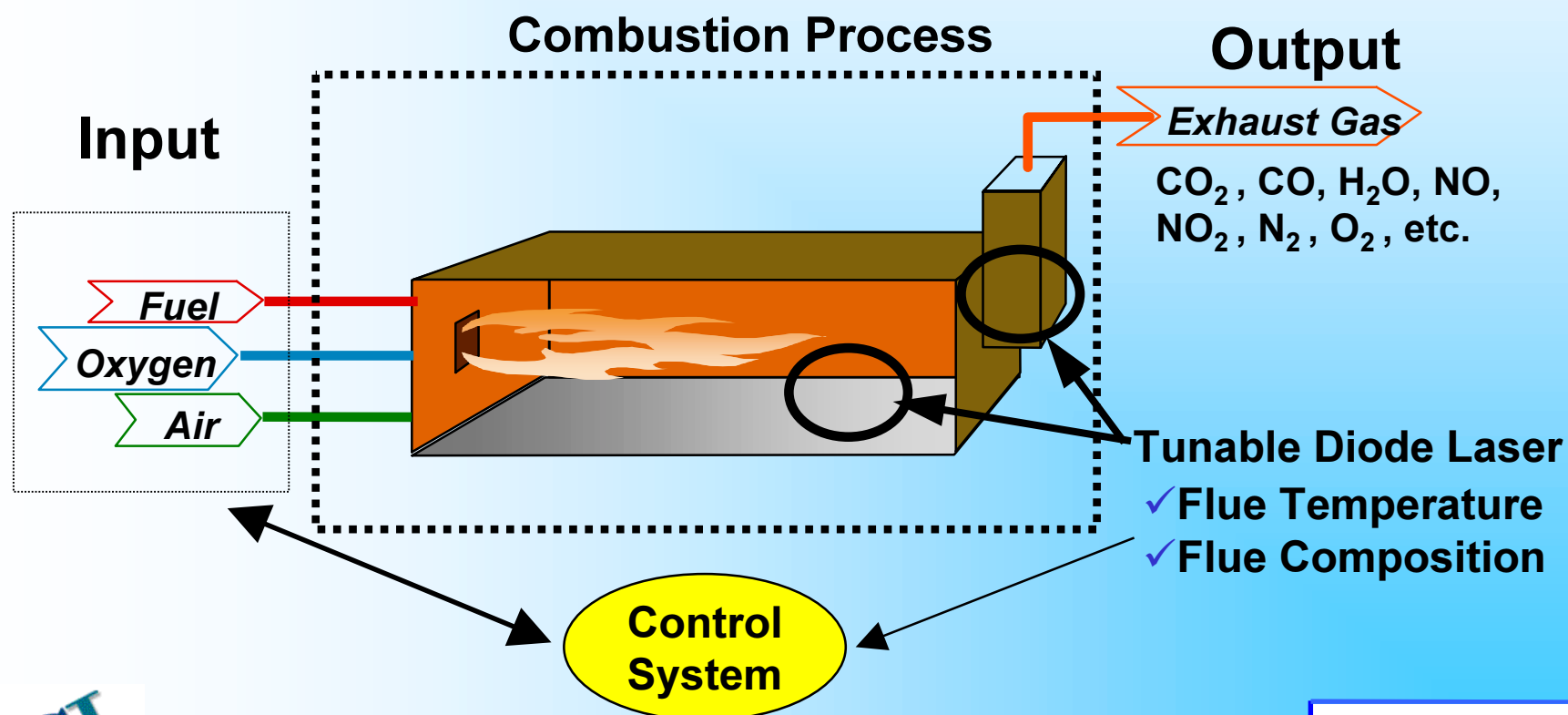
- **Motivation**
- **Project Team**
- **Technology Description**
- **Project Status**
 - **TDL Development**
 - **Pilot Test Platform**
- **Project Planning**
- **Budget Review**





Objective

To fabricate and test an industrial multi-gas diode laser sensor system for **O₂**, **CO**, and **T**emperature monitoring for high temperature harsh environments.





TDL Technology Advantages

- ✓ **Developed around telecommunication components**
 - Near-IR diode lasers operate near room temperature
 - Fiber optic compatible
- ✓ **Fast response time**
 - 10 msec measurement time
 - Time averaged 10 Hz sampling rate
- ✓ **Simple electronic detection**
 - Reduced cost
 - Compact
- ✓ **Multi-functional**
 - Multiple-species
 - Temperature



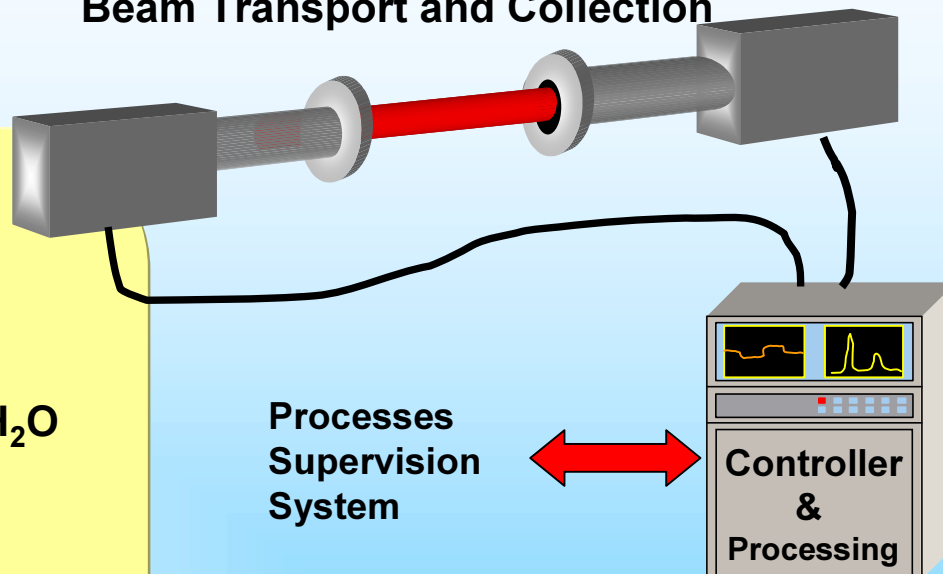


Project Objective

System Features

- ✓ Harsh Environment Acceptable
 - $T > 1600\text{ }^{\circ}\text{C}$
 - High Particle densities
- ✓ Multi-species Monitoring O_2 , CO , H_2O
- ✓ Multi-functional
 - Temperature
 - Air Entrainment
 - Particle Density
- ✓ Fast-Time Response 1-10 Hz
- ✓ Calibration Free
- ✓ Integrate with Processes Control
- ✓ Autonomous Operation
- ✓ Cost Effective

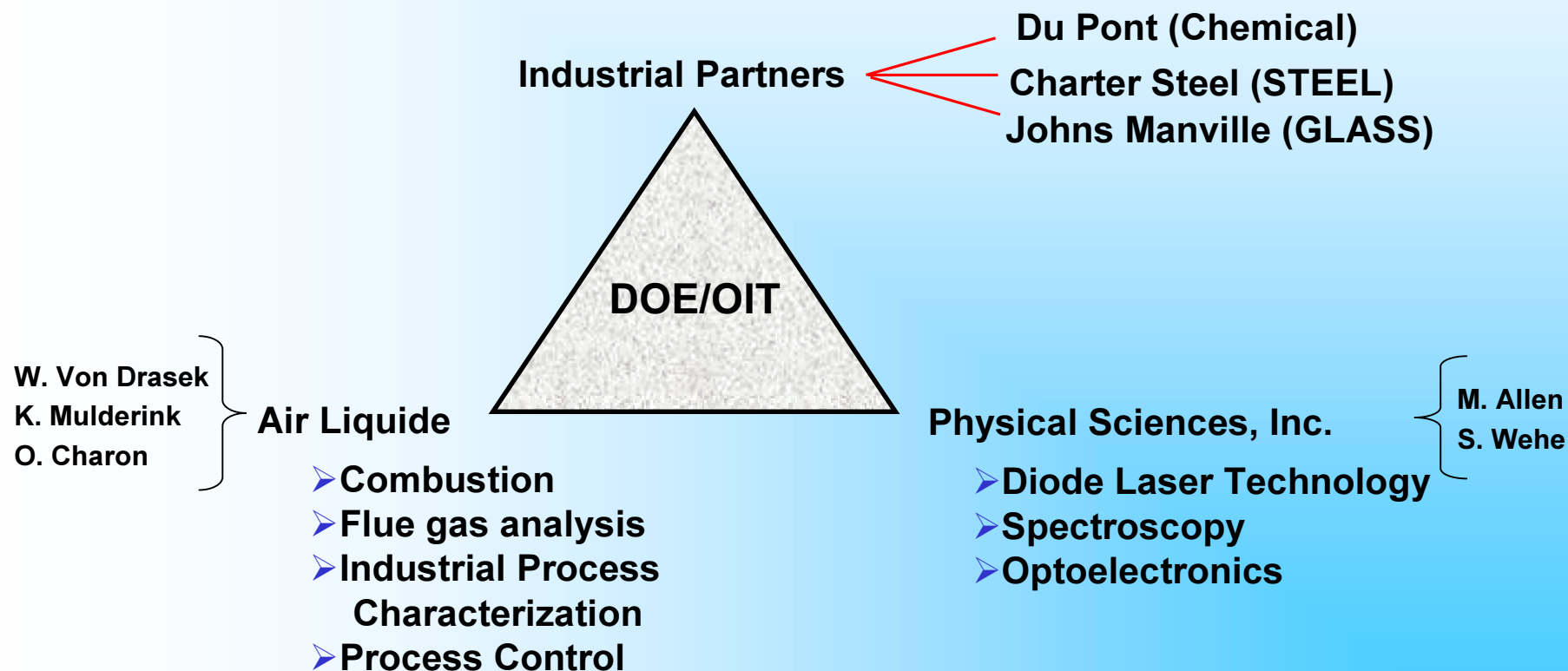
Beam Transport and Collection



- System Ready for Testing *Sept.-Nov. 2001*



To address the technical issues associated with traditional monitoring techniques Air Liquide and Physical Sciences, Inc. formed a project team for the development of an **Advanced Sensor** utilizing **Tunable Diode Laser Technology**.





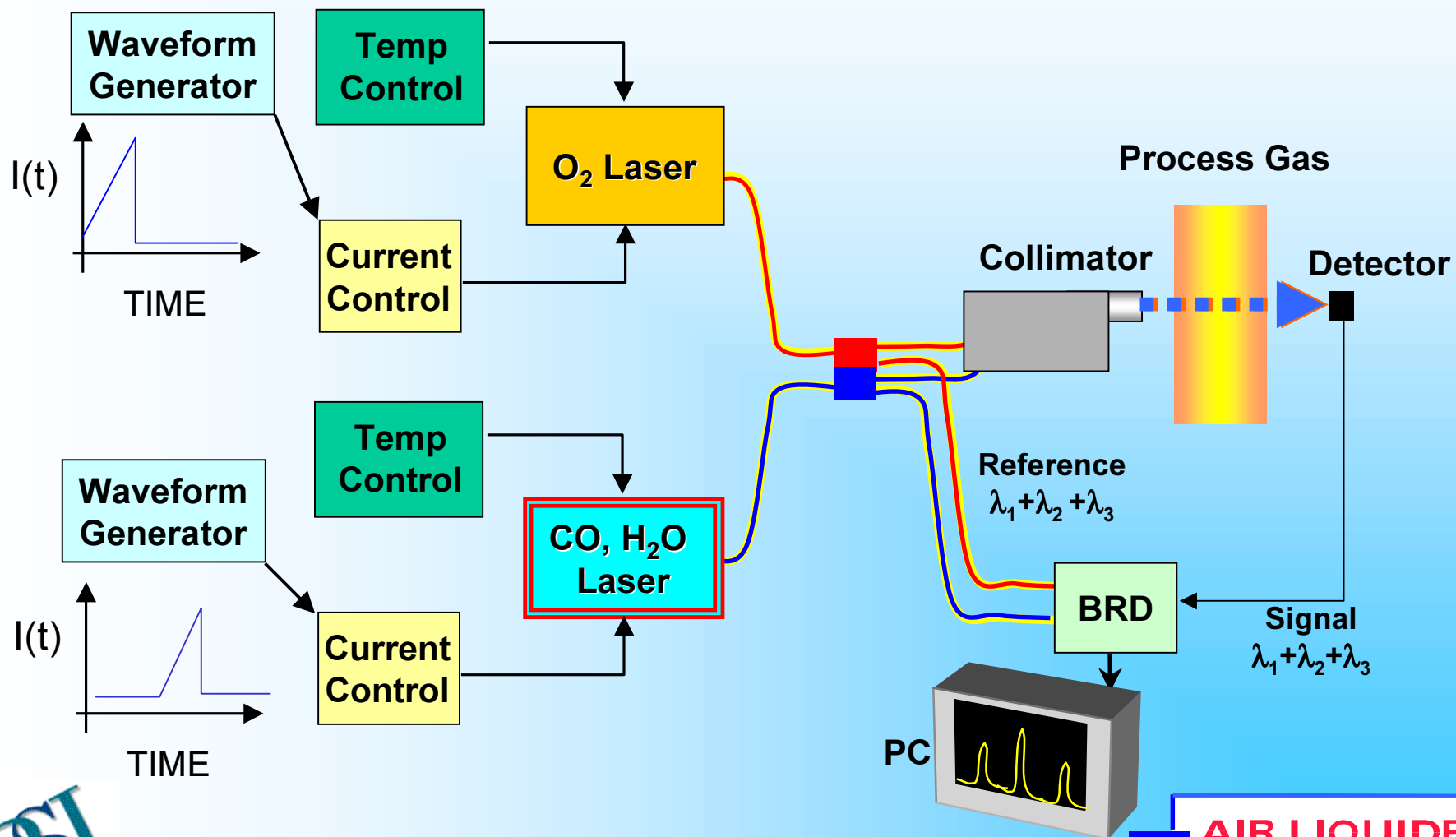
IOF Partners and Applications

<i>Industry</i>	<i>Partner</i>	<i>Application</i>	
GLASS	Johns Manville	Fiber Glass Melting Tank <ul style="list-style-type: none">•Energy Efficiency•NOx Reduction	
CHEMICAL	Du Pont	Sulfuric Acid Recovery <ul style="list-style-type: none">•O₂ Optimization•NOx Minimization	
STEEL	Charter Steel	Reheat Furnace <ul style="list-style-type: none">•Energy Efficiency•Scale Reduction	EAF Furnace <ul style="list-style-type: none">•Energy Efficiency•Carbon Balance





Multi-species Measurement Strategy

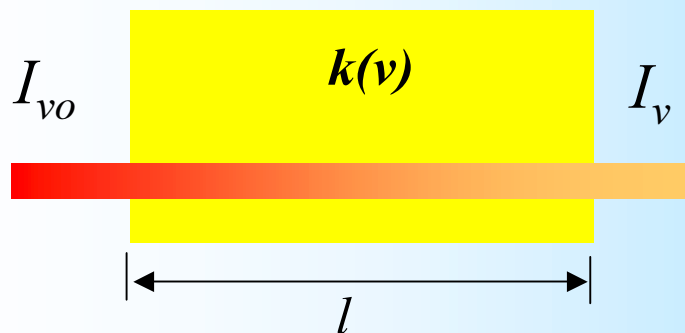




Resonant absorption described by the Beer-Lambert Relation:

$$I_v = I_{v,o} \exp \left[- \underbrace{S(T)}_{\text{Linestrength}} \underbrace{g(v - v_o)}_{\text{Lineshape}} \underbrace{Nl}_{\text{Number Density X Pathlength}} \right]$$

Linestrength Lineshape Number Density X Pathlength



Number Density

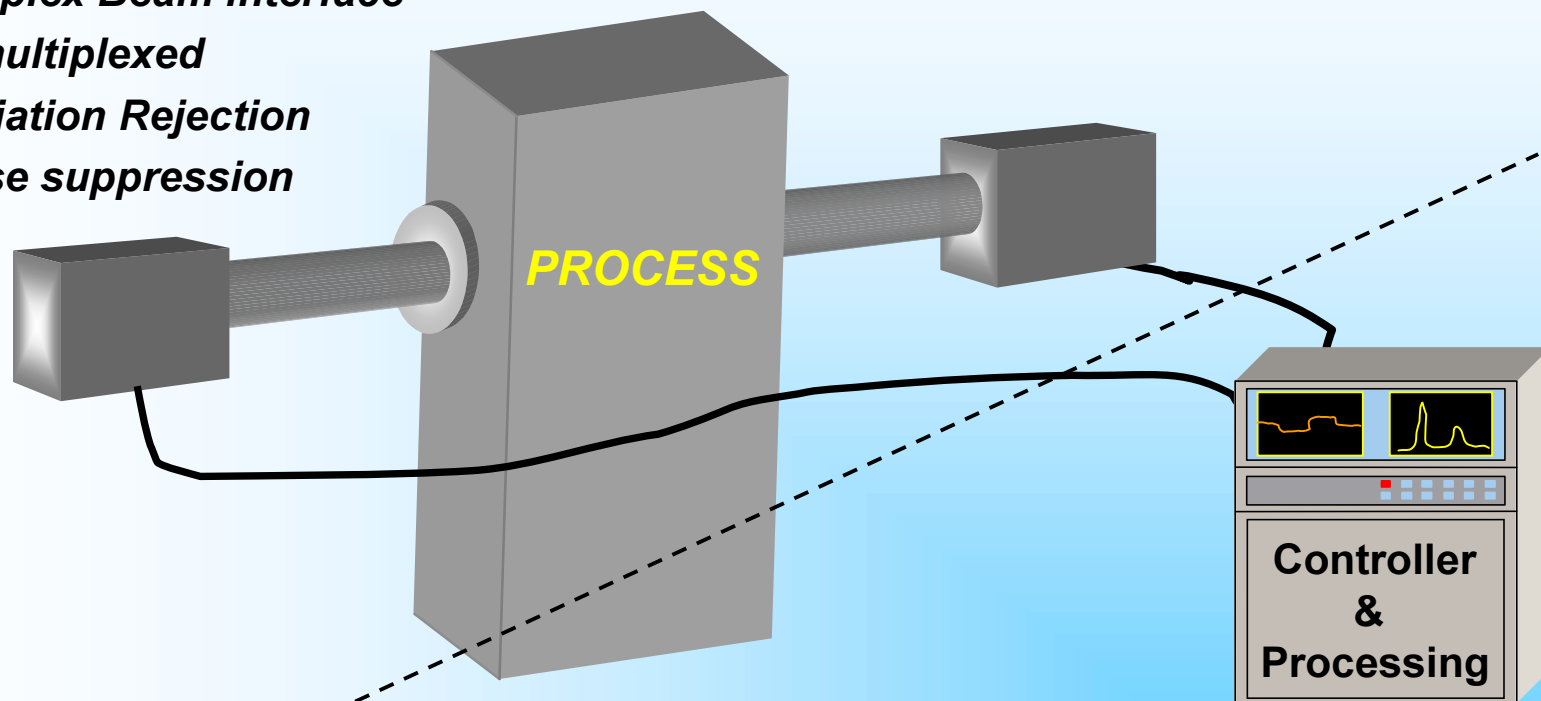
$$N = \frac{1}{S(T)l} \int \ln \left(\frac{I_{vo}}{I_v} \right) dv$$



Technology Development Considerations

① Beam Transport and Collection Two Separate Technology Development Issues

- ✓ *Multiplex Beam Interface*
- ✓ *Demultiplexed*
- ✓ *Radiation Rejection*
- ✓ *Noise suppression*



② Laser System

- ✓ *Control Circuitry*
- ✓ *Signal Circuit (BRD)*
- ✓ *Multiple Laser Integration*

Processes
Supervision
System





Technology Developed in DoE Program

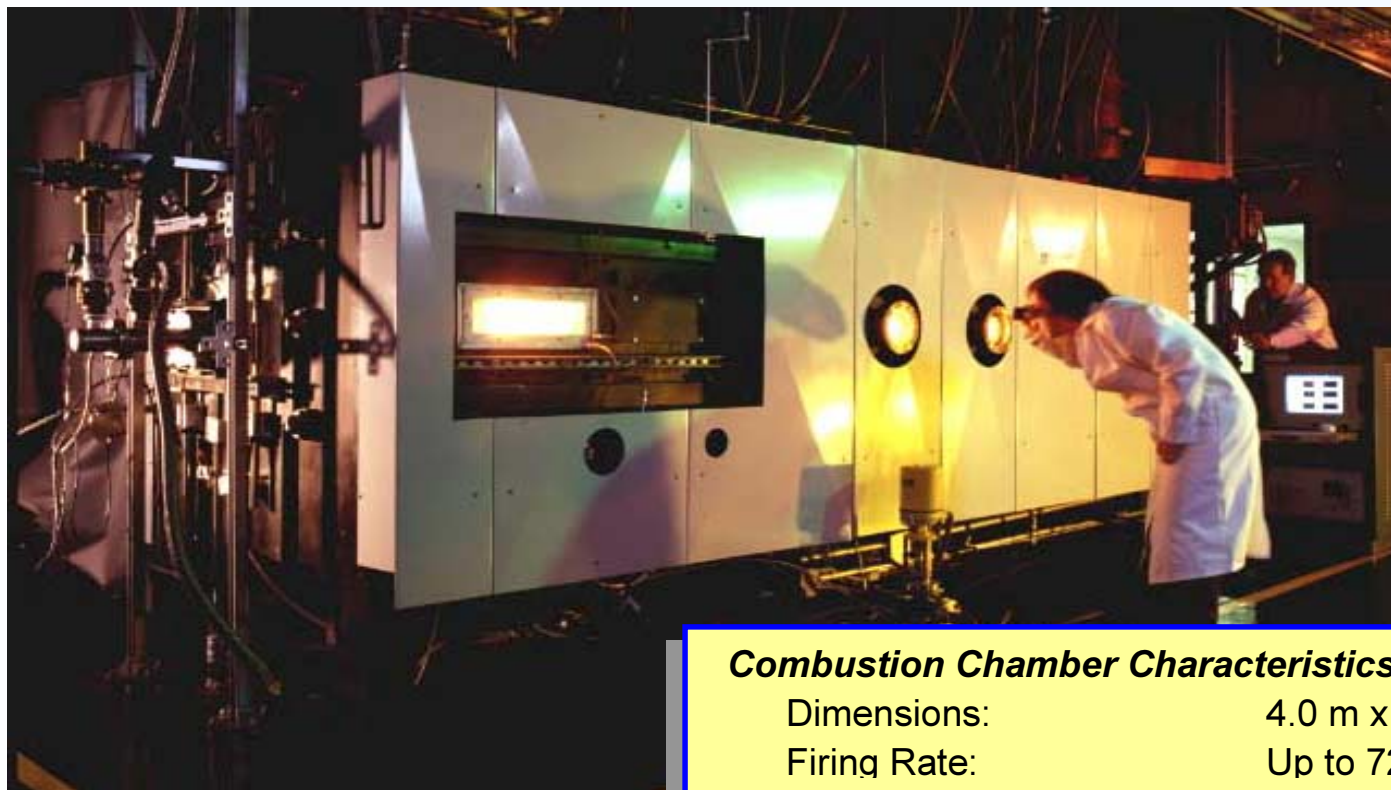
- **Multi-parameter Sensor system**
 - O₂
 - CO
 - H₂O
 - Temperature
 - **BRD Industrial Testing**
 - Cost effective
 - Reduce system complexity
 - **HT Spectroscopy**
- Evaluation on a Diverse Range of Industrial Processes*



Chicago Research Center



700 kW Oxy-Fuel Pilot Furnace



***Oxy-Fuel
or
Air-Fuel***

Combustion Chamber Characteristics

Dimensions:	4.0 m x 1.0 m x 1.0 m
Firing Rate:	Up to 720 kW (varying load)
Operating Temperature:	Up to 3000°F (1650°C)
Heat-up rate:	Up to 500 °C/h
Controls:	PLC and PC Supervision (Real Time Heat and Mass Balance)



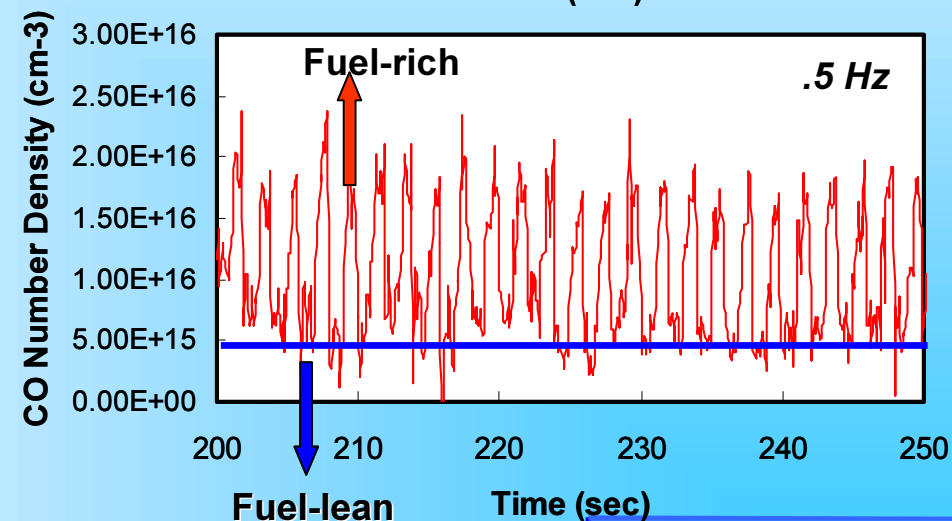
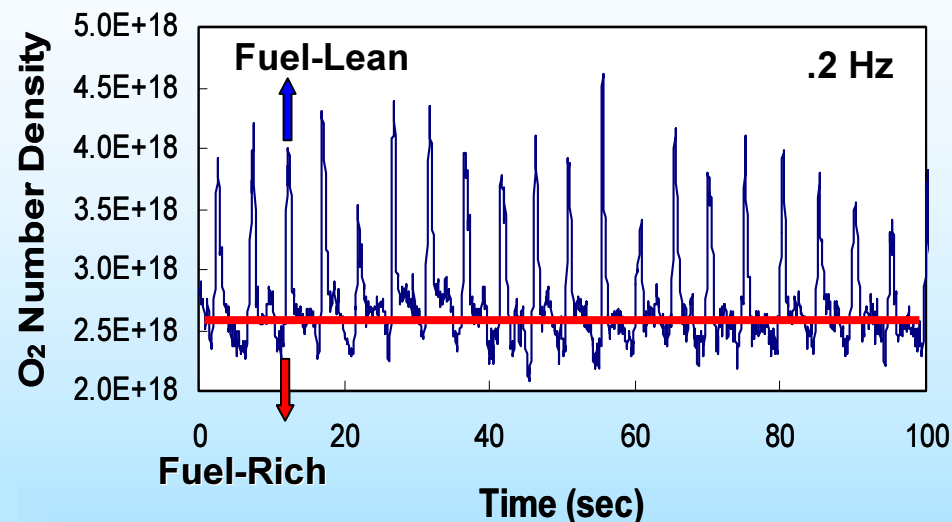
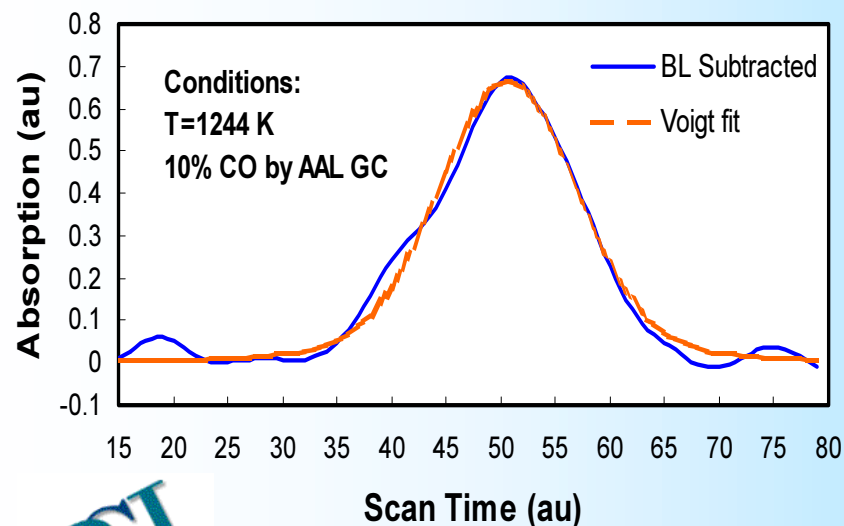
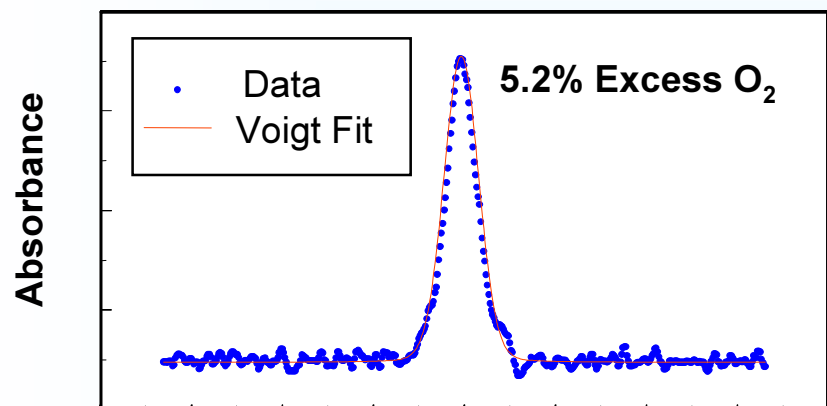
AIR LIQUIDE

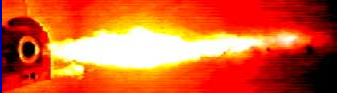
RESEARCH AND DEVELOPMENT



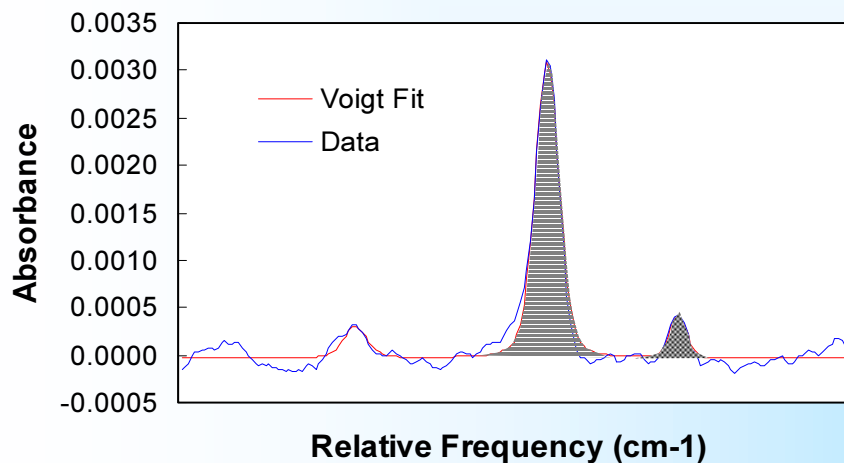
Dynamic Process Monitoring

440 kW





Temperature Measurement



O_2 lineshape at 1540 K, 100 cm path

Temperature

$$R = \left(\frac{S_1}{S_2} \right)_{T_o} \times \exp \left[\frac{-hc\Delta E}{k} \left(\frac{1}{T} - \frac{1}{T_o} \right) \right]$$

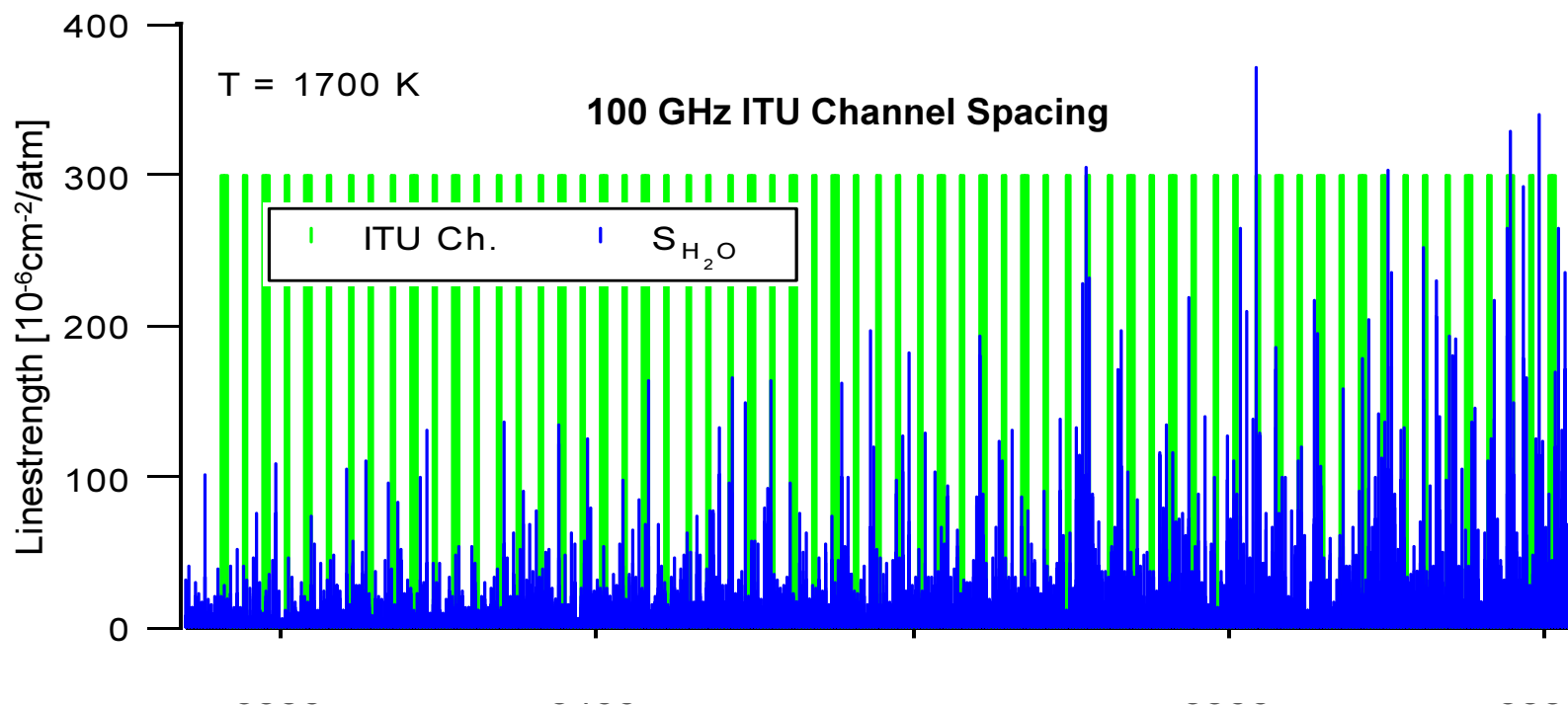
Ratio of integrated absorbance
for two transitions

Sample	TDL	ST	% Error
1	1756	1702	3.17274
3	1632	1613	1.17793
2	1477	1540	-4.0909

• Ref. $T = 1495 \text{ K}$



LINE SELECTION PROCESS



Over 28000 Lines Accessible!





Selection Process Criteria

H₂O Present at High Concentration Levels in all Combustion Processes

- **Line Selection Process (*HITEMP*)**

- ✓ **Optimum Energy Separation,**

$$\Delta E'' = 2T \frac{k}{hc}$$

- ✓ **Minimum Linestrength Required, S_{min}**

- ✓ **Spectrally Isolated**

- ✓ **Spectrally accessible ($1.5 \mu m$)**

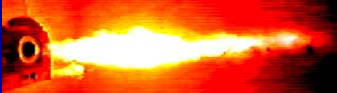
- ✓ **Validation Required (*Experimental*)**

Two Pair of H₂O
lines Best Solution

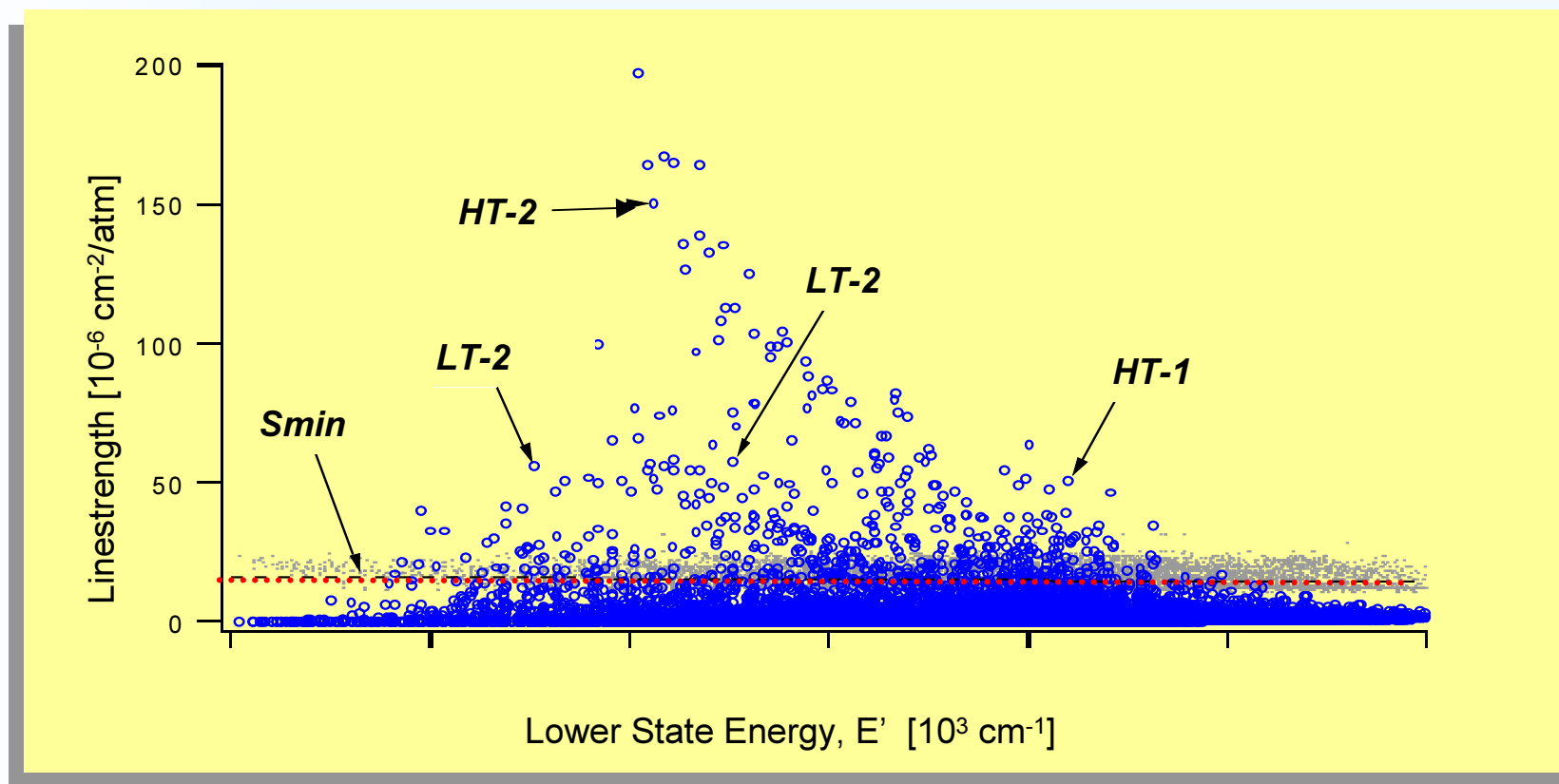
LT → Low Temp

HT → High Temp



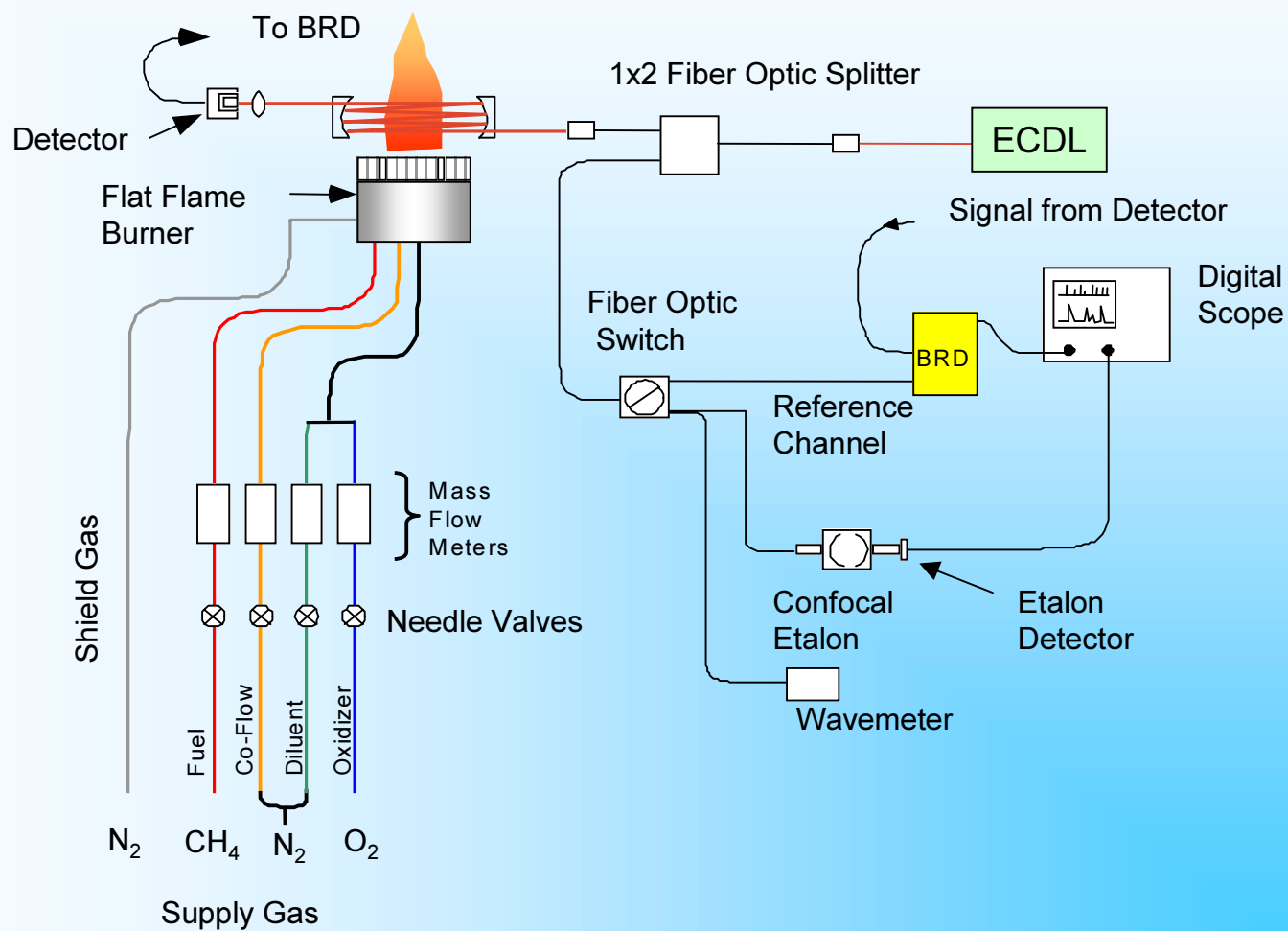


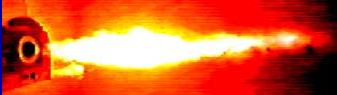
Theoretical HITRAN Selection





LABORTORY SETUP





Spectral Survey Summary

Empirical Line Selection

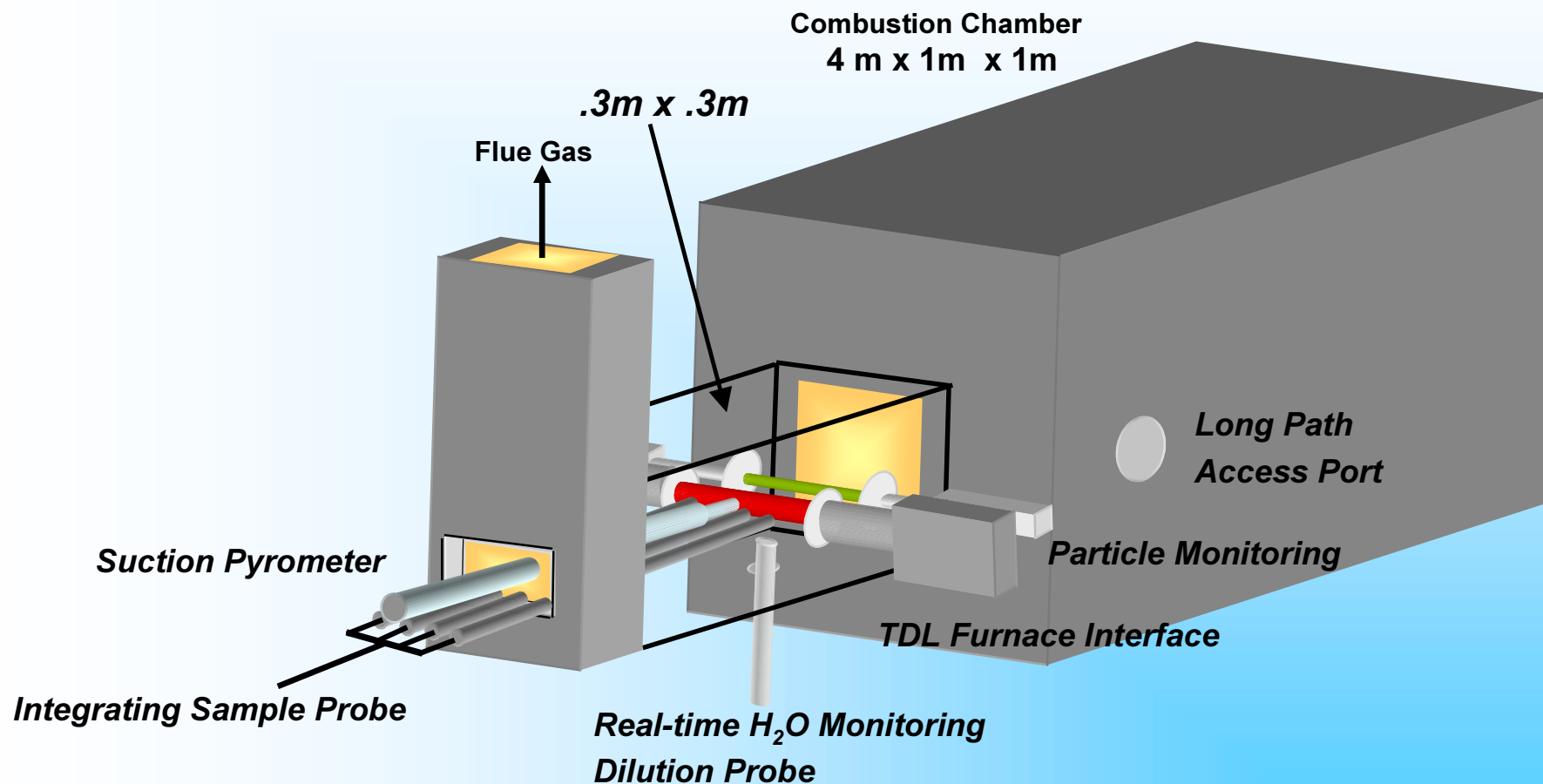
- 25 lines examined
 - ✓ Yield 300 possible line pairs
- 7 lines Identified
 - ✓ Good SNR
 - ✓ No Interference
 - ✓ Low Temp pair ± 15 K
 - ✓ High Temp pair ± 35 K
 - ✓ Near Isolated CO line

Laser Selection Completed



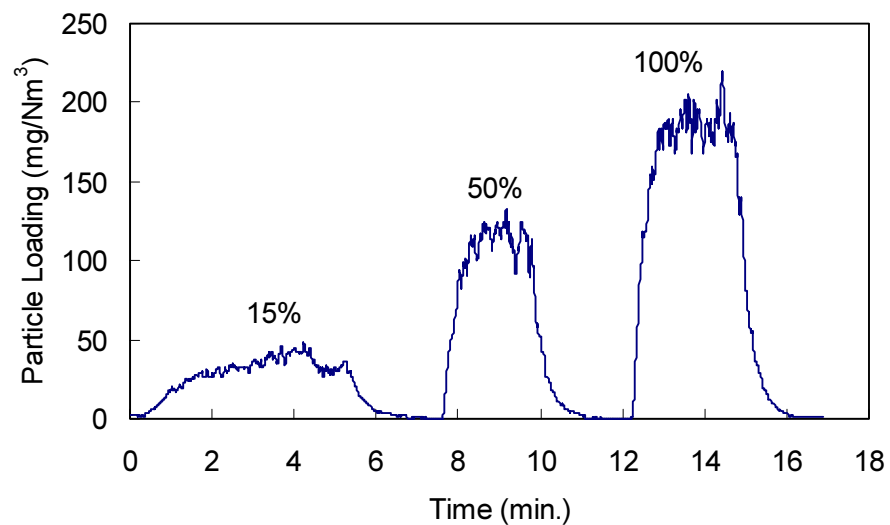
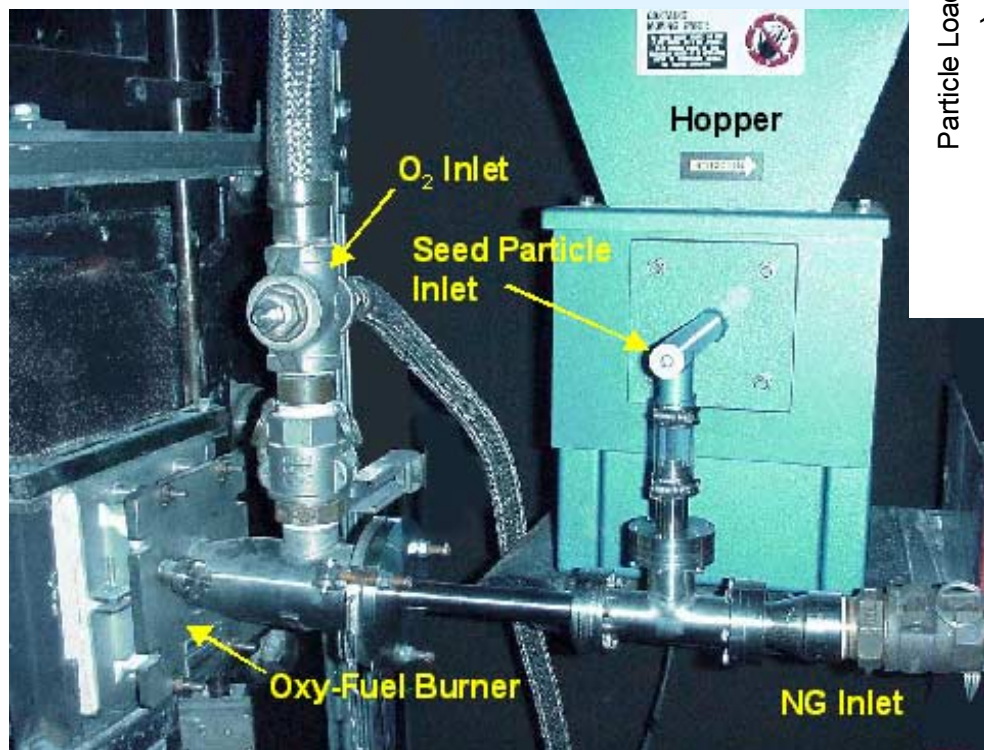


FLUE GAS CHARACTERIZATION





Dirty Process Gas Simulator

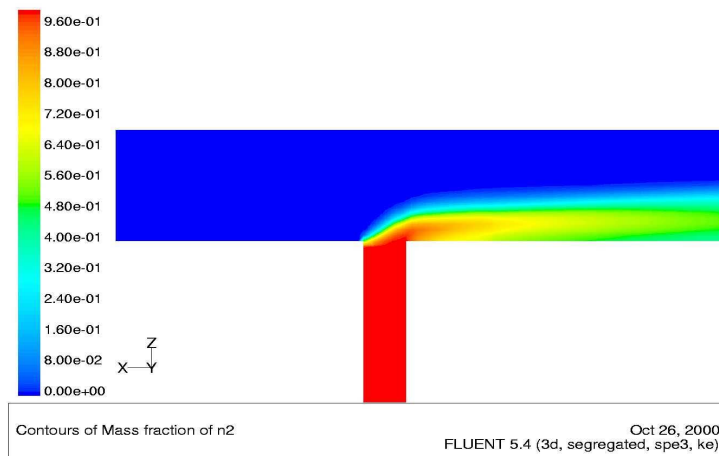
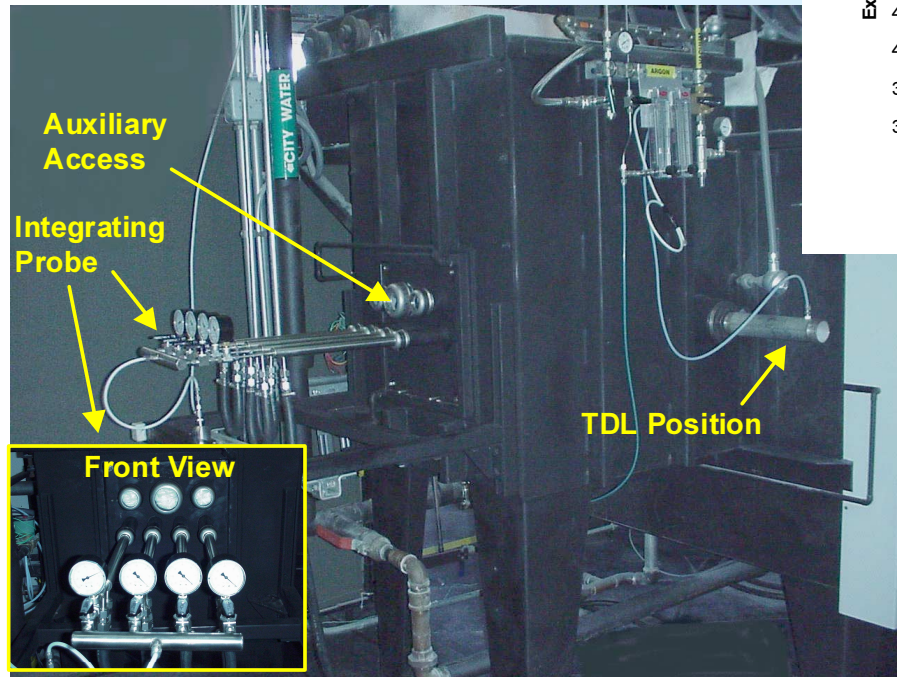
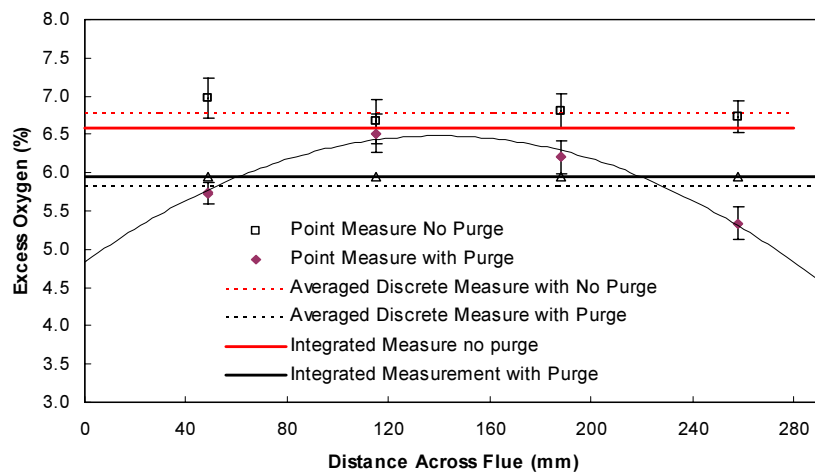


Seed Particles

- Al_2O_3
- ZrO_2

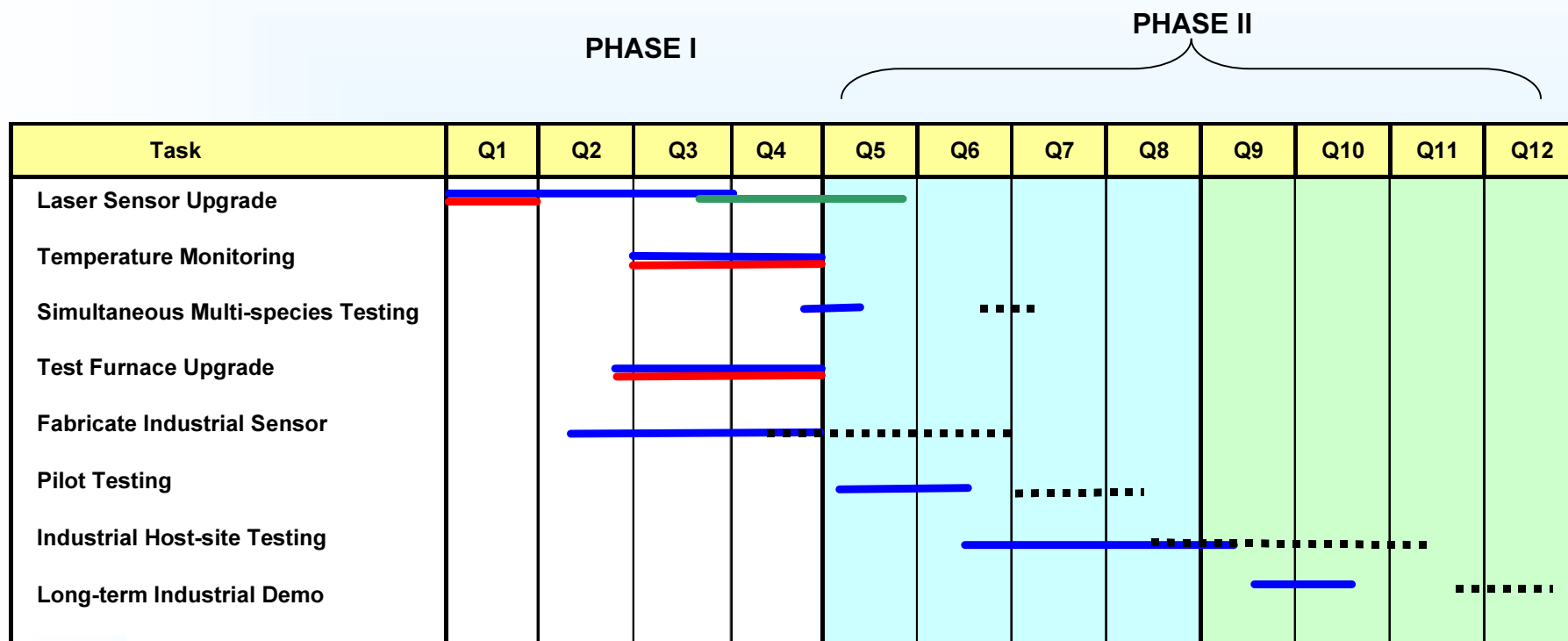


Integration Sampling Probe





Milestone Status



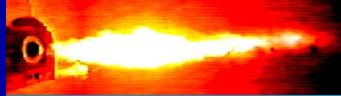
Planned ————

Completed ————

Extended ————

Shifted





Project Budget Status

